Turbine generator v selection criteria for r and man

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Design and operation issues influence correct transducer selection and installation techniques for vibration measurement on turbine generators. Part 1 of this article will define a methodology for correct transducer selection. Part 2 (in a subsequent issue) will present installation considerations and techniques.

Turbine generators, which are typically composed of high pressure (HP), intermediate pressure (IP), and low pressure (LP) turbine casings, a generator, and an exciter, are relatively complex mechanical systems that incorporate a wide variety of design features (Figure 1). All turbine generators are supported on a foundation block, which may be a concrete structure or a steel fabrication, which has a considerable influence on the dynamic behavior of the machine train. The whole assembly of rotors, casings, bearing supports, and foundation must be considered when selecting transducers for effective machinery management.

The selection of vibration and position measurement transducers also requires consideration of the design of individual casings within the turbine generator train and the effects of coupling between their rotors. Traditional methods of vibration measurement are based on manufacturer's preferences, influenced by corporate end user preference, and sometimes national standards. Installed systems on older turbine generators and newly commissioned units may not be adequate for either the protection of the machines or their management. Installations may be inadequate because of wrong transducer type or insufficient measurement points. Most original Turbine Supervisory Instrumentation (TSI) systems were specified without consideration of the need for continuous acquisition of information for diagnostics and machinery management.

Machinery protection and machinery management

Any turbine generator set is an extremely expensive investment. Protection and management of the

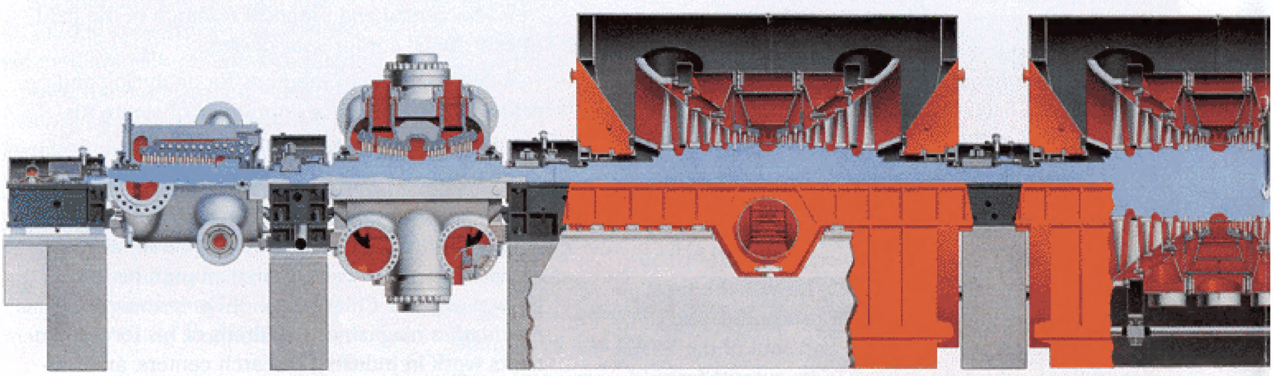

Figure 1. Cross-section of dynamically com

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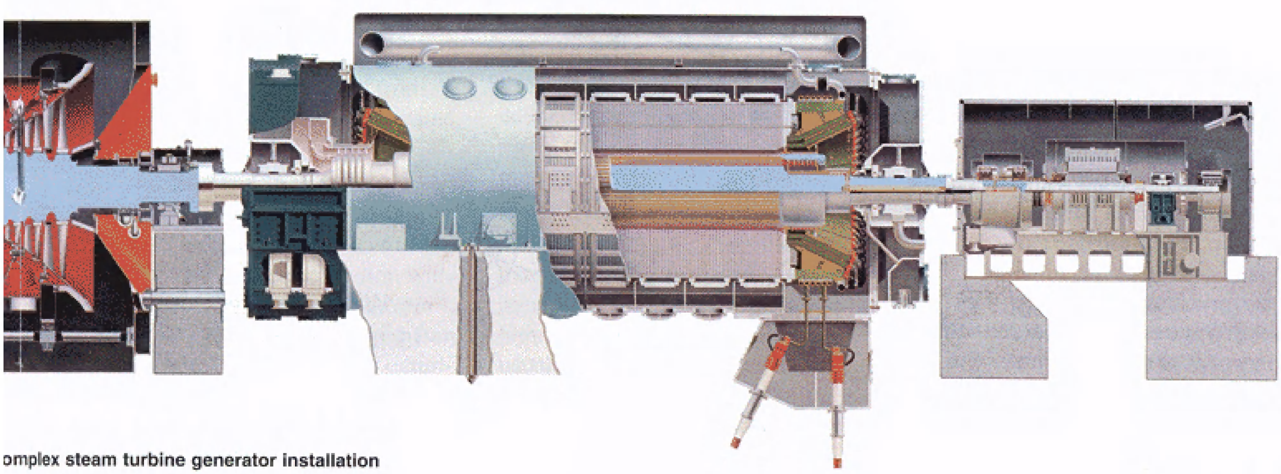
asset throughout its planned operational life is essential. Information derived from inadequate transducer systems may be inaccurate and misleading. Effective machinery protection may not be achieved. Losses of production may occur because a machine is tripped or manually shut down unnecessarily because indicated vibration levels are spuriously high. A trip may be missed because the indicated vibration level is low and does not reveal the true severity of the dynamic forces applied to the rotor or bearing structure. Similarly, effective management of the asset cannot be achieved if the transducer installation provides insufficient or misleading measurements. Vibration transducer requirements for fully effective machinery protection and fully effective diagnostics / machinery management are similar. It is neither necessary nor desirable to use separate transducer installations for machinery protection, diagnostics, and management. However, machinery management applications may require additional vibration measurements; for example, the use of "Mode Identification Probes" to more completely describe the coupled mode shapes of the machine (Figure 2).

This article addresses the selection of transducers for shaft vibration and radial position measurements specific to turbine generators. Many additional measurements, though, are required to achieve effective machinery protection, diagnostics, and management. These include machine and process variables, such as temperatures, pressures, and electrical parameters, which define the turbine generator's operating state.

Machinery protection is provided when vibration (or other) measurements are installed permanently on a machine and connected to a dedicated machinery protection system. The machinery protection system has alarm setpoints (typically Alert and Danger), which automatically activate an alarm when a predetermined level is reached. The machinery protection system may have alarm relays which can automatically shut down (or trip) the machine. Alternatively, instructions to shut down the machine may be issued by an Operator when an alarm occurs. Machinery protection is necessary and valuable since it



omplex steam turbine generator installation

can prevent machine damage and consequential losses in the event that a sudden machinery or process malfunction occurs. The traditional role of a TSI system includes a machinery protection function.

In any event, due consideration should be given to the consequences of a turbine generator trip (either automatically or through Operator action) based on high vibration. In many cases, the risk to the turbine generator and associated plant equipment is much greater as a result of a sudden trip from high load operation than a short period of operation during which vibration alarms are investigated using a management system.

A machinery management system uses the data provided by the machinery protection system, supplemented by additional machine and process measurements, to define the true operation state and condition of the machine. The machinery management system provides all of the information necessary to optimize the machinery in terms of operational safety, maximized service life, minimized maintenance cost, and energy efficiency.

In the current business environment, machinery protection alone cannot provide adequate information to ensure that the machinery is operated optimally. There is a considerable amount of valuable information obtained by the transducers and monitoring system. When used with a machinery management system, it can provide early identification of machinery malfunctions before a protection system would cause an alarm or trip. In fact, a machinery management system considerably increases the usefulness of a machinery protection system by providing **"actionable information"** to Operators and Engineers, which they can use to prevent a sudden plant trip or emergency shutdown of the machine or process.

Bently Nevada Data Manager® 2000 and Machine Condition Manager™ 2000 Systems

The shaft relative and bearing absolute vibration signals from the machinery protection system must be interfaced to Data Manager 2000 using TDIX or TDXnet Communications Processors. Acquisition of dynamic and static information during startup and shutdown is essential on turbine generators. Other machine and process measurements are integrated into the Data Manager 2000 databases either through additional monitor channels or from the Distributed Control System (DCS) by digital interconnection. Based on information acquired during startup and during the loading and daily operation phases, a meaningful assessment of the machine train characteristics can be performed.

Appropriate Alert and Danger setpoints can be determined for shaft relative, bearing seismic, or shaft absolute measurements. Shaft relative is the default measurement for Danger alarm and/or automatic shutdown for machinery protection. Only in cases where the bearing absolute vibration is significant should bearing absolute vibration be selected for machinery protection - these issues are addressed in detail later in this document.

Correct application of Data Manager 2000, including the configuration of appropriate software alarms, such as "Acceptance Regions" for all vibration measurements, provides the means to detect change in machine behavior at an early stage in the development of a problem.

Bently Nevada Machine Condition Manager 2000 provides additional capability to predict turbine generator malfunctions at an early stage. Using expert system principles incorporating comprehensive knowledge bases and rule sets, Machine Condition Manager

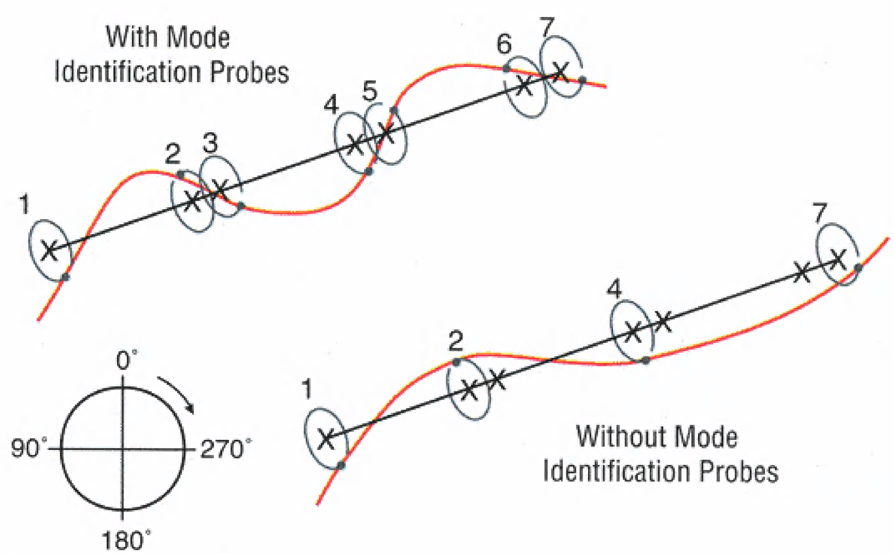


Figure 2. Resolution of complex mode shapes is made possible by Mode ID probes.

2000 provides an automated diagnostics capability with multilevel "Advisory" alarm messages for Operations and Maintenance personnel. Whenever a significant machine event occurs, even before annunciation of a first level "Alert" alarm on the monitor, Machine Condition Manager will provide Operators with specific reports and recommended actions.

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Radial Vibration Measurements

Two distinct types of radial vibration measurements can be applied to turbine generators:

1. **Relative vibration** - vibration measured with respect to a component of the machine. Proximity probes measure shaft dynamic motion, and position, relative to what the probe is mounted on, usually the bearing or bearing housing.

2. **Absolute vibration** - vibration measured relative to an inertial (fixed) reference frame. Accelerometers and velocity transducers measure absolute vibration, typically of machine housings or structures. Therefore, they are referred to as seismic or inertial transducers.

Traditionally, turbine generators have been equipped with proximity or seismic vibration transducers, according to preference. In some instances, manufacturers adopted methods of measuring the shaft absolute vibration using a mechanical probe which contacted the shaft surface, but was decoupled from the bearing housing by a lubricated sliding bearing.

The so-called shaft rider transducer, when in perfect condition, enabled a seismic transducer to follow the shaft dynamic motion within a narrow frequency band from about 500 cpm up to approximately 7200 cpm. The potential for deterioration of the contacting tip and friction in the sliding bearing was considerable. Intermittent contact between the probe and the shaft also caused inaccurate measurements. The availability of the combination of the seismic transducer and noncontacting proximity probe, which also provides shaft radial position measurements (impossible with a shaft rider), rendered this type of probe obsolete about 30 years ago.

This dual probe transducer set consists of a proximity probe and a seismic transducer installed at approximately the same point (usually in a common transducer housing on the machine bearing housing). Four separate measurements are provided by this transducer system:

Shaft relative radial position (displacement), relative to the probe mounting location, measured by the proximity probe.

Shaft relative radial dynamic motion (displacement), relative to the probe mounting location, measured by the proximity probe.

Machine casing absolute vibration, measured by the seismic transducer.

Shaft absolute motion, represented by the summation of the seismic signal (after integration to displacement) and the shaft relative displacement signal.

Typically, during a retrofit of a machine, a dual probe type arrangement replaced the shaft rider system. The shaft rider system was usually mounted onto the bearing housing via a bolted flange. A tube (sleeve) allowed the shaft rider tip to contact the shaft (that is "ride on the shaft"). Typically, when dual probes were installed, the shaft rider sleeve was modified to accept the dual probe (or a new sleeve arrangement was fabricated). It is important to note that with this type of dual probe installation, all shaft relative position and shaft relative vibration is measured referenced to the outer bearing housing. This installation practice conveniently reduced installation complications and cost, but increased the potential for measurement inaccuracies.

Seismic vibration of the bearing cover measured by the velocity transducer element of the dual probe may be totally unrelated to the bearing vibration. Structural resonance of the cover can lead to grossly inaccurate measurements of casing and shaft absolute vibration.

Shaft radial position can be very inaccurate, since the bearing cover on many turbine generators is not mechanically referenced to the bearing.

Inaccurate shaft relative vibration measurements can result from transverse mechanical resonance of the existing mounting tube or sleeve, which must extend as much as 38 centimetres (15 inches) to the shaft surface. There is the potential for fatigue failure of the probe sleeve, even where a bracket has been used to stabilize the sleeve.

Note: *Most transducers measure vibration in only one direction. It is essential to measure shaft vibration and position in two orthogonal axes for a 2-dimensional (cross-section) view at each bearing location or sup-*

plementary (mode identification) location. This provides vital rotor orbit, shaft average centerline position, and mode shape information.

Comparison of the benefits of shaft relative and shaft absolute measurements

Some individuals and institutions argue that shaft absolute measurements are essential to correctly determine vibration severity and carry out effective balancing of turbine generators. The rationale is that only absolute vibration measurement can truly indicate the dynamic motion of a rotor because the measurement is inertially referenced. However, in a practical machinery application, shaft absolute motion is not as meaningful as shaft relative (to bearing) motion, supplemented by bearing housing absolute motion where necessary.

If the dynamic motion of the bearing is zero, the shaft relative motion is identical to the shaft absolute motion. It is in circumstances where the bearing dynamic motion is not zero that the deviation between shaft relative and shaft absolute measurements becomes progressively more significant (Figure 3). The system stiffness characteristics of a turbine generator may result in bearing motion of significant amplitude, either as a design characteristic or as a result of a malfunction.

During machine startup or shutdown, the Dynamic Stiffness of the system will change. In fact, the Dynamic Stiffness of each bearing support will change in a unique manner related to the mechanical design of the individual pedestal, and there will be combined system effects which affect groups of bearings interactively. It is important to recognize that the meaningful stiffness of a turbine generator bearing, support structure, or foundation is a complex variable, involving the spring stiffness, damping (quadrature) stiffness, and mass stiffness of the structure. Since quadrature stiffness and mass stiffness are involved, Dynamic Stiffness varies in a nonlinear manner in response to changes in the frequency of excitation.

It is important to recognize that, regardless of the magnitude of bearing absolute vibration, the shaft relative vibration measurement provides the correct information about the relative motion of the rotor in its bearing clearance.

However, in circumstance where the bearing absolute vibration magnitude is significant, equal, or much larger in magnitude than the shaft relative vibration, the shaft relative vibration measurements may need to be supplemented by bearing absolute vibration measurements.

Depending on the phase relationship between the shaft relative vibration and the bearing absolute vibration, the shaft absolute vibration may be considerably different in magnitude than the relative measurement. The relative measurement may not alone indicate the significance of the vibration, for example, if there is structural weakness or looseness of a bearing pedestal or related structure.

Conventionally, the conclusion in these circumstances has been that it is necessary to measure shaft absolute vibration. In fact, this is at best questionable and may be incorrect. This is because shaft absolute vibration measurement conceals the relationship between shaft relative to bearing vibration and bearing absolute vibration. It is, therefore, impossible to properly understand the machine's behavior

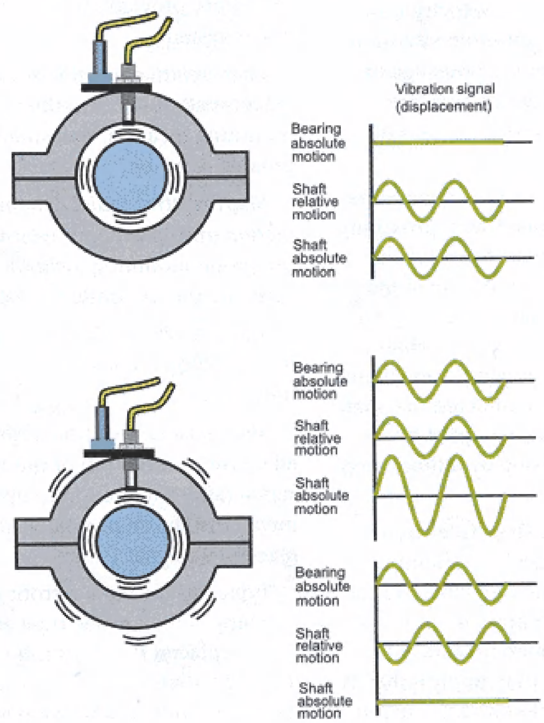

Figure 3. Comparison of bearing and shaft measurements. Shaft relative motion, which represents how much clearance is used, is not directly related to shaft absolute motion.

using shaft absolute vibration alone, even when an XY probe pair is used. The following case illustrates this principle.

The generator of a Turbine Generator set has high shaft absolute vibration in the vertical plane. The customer concludes that the bearing clearances have increased. Subsequent analysis of shaft relative vibration, shaft average centerline (radial) position, and bearing absolute vibration by our Machinery Management Services Engineers showed that neither shaft relative vibration nor shaft radial position had changed. The bearing absolute vibration, though, had increased approximately in-phase with shaft absolute vibration.

This machine has a foundation resonance close to operating speed. The electrical system frequency varies significantly at particular times of the day, and causes the rotor 1X frequency to tune closer to this resonance. This causes the shaft absolute vibration to exceed the maximum allowable level at these times.

Conclusion

If the customer had observed shaft relative vibration and radial position together with bearing absolute vibration, it would have been clear that the bearing was not damaged. The low Dynamic Stiffness of the bearing support/foundation implied low forces were applied to the bearing - a shutdown and subsequent bearing inspection were not required on an urgent basis.

Of course, if the bearing absolute vibration had been low in amplitude and no evidence of a foundation resonance was observed, bearing damage would have been positively identified by observation of the shaft relative vibration vectors, orbit, and shaft radial position.

In circumstances where bearing vibration is known to be of significant magnitude, or is believed to be significant under special circumstances, it is essential to measure both shaft relative and bearing absolute vibration. It is also essential to retain the separate signals for processing and conversion to meaningful information.

Unfortunately, it is difficult to predetermine this requirement. A criteria, based on a percentage amplitude relationship (for example, 20%) between shaft relative vibration and bearing absolute vibration, is inadequate and is also hard to apply meaningfully. It may not be practical to establish the percentage in advance of system definition, for example, on an untested new machine design. If measurements are possible on a machine which is being retrofitted, it may be only feasible to obtain bearing absolute vibration data. Moreover, measurements are likely to be available only for a machine operating under normal conditions. It is invalid to assume that, under malfunction conditions, the shaft-relative to bearing-absolute vibration ratio will not be changed; for example, if the bearing pedestal is loose, a foundation crack develops, or when extremely large unbalance conditions are present on the rotor.

Another benefit of shaft relative measurements is the position information that is part of the measurement. Typically, it is the position of the shaft within its bearing clearance. This measurement complements the vibration information during transient and steady state operation. It also provides information about the machine's condition when the machine is stopped or at slow roll speed, when we don't expect, or can't get, vibration information. Position information is critical to the evaluation of the vibration data and is vital to the success of the machinery management systems.

The position of the shaft within the bearing clearance defines the loads that are acting on the shaft and housing. A low level of vibration does not guarantee there is not a problem. Vibration is the result of forces and Dynamic Stiffness. If the stiffness is high, due to increased loading on the bearing (due to pumping loads, internal or external misalignment, etc.), the position measurement is likely to be the defining variable rather than the vibration.

Relative position can also be a precursor of problems. If the average position of the shaft is moving away from its normal location, towards the center of the bearing, this could be an indication of alignment problems. If the trend continues, it is an indication of a potential fluid-induced instability problem resulting in high vibration leading to a possible rub condition and machine trip.

Position information has a defining role in machinery management and in the rule sets used to generate recommended actions. Besides shaft relative radial position, other important position measurements include axial (thrust) position, differential expansion, casing expansion, valve position, and alignment.

For more information on Data Manager® 2000 or Machine Condition Manager™ 2000, see the Reader Service Card in this issue.

References

1. Bently, D.E., Hatch, C., Jesse, R., Whiteley, J., "Dynamic Stiffness in Whirl and Whip," Orbit, BNC, March 1998.
2. Bently, D.E., Muszynska, A., Littrell, N., "Margin of Stability," Orbit, BNC, June 1996.